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PROBABLE FUNDAMENTAL CAUSES OF RED TIDE OFF THE WEST COAST OF FLORIDA[1]

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The recent outbreak of Red Tide and the consequent death of very large numbers of fishes on the west coast of Florida were subjects of investigation by the scientific staff of the Marine Laboratory during the first half of the year 1947. The results of these investigations are published in detail elsewhere (Gunter, Davis, Williams, and Smith 1948). These results together with the observations of a number of other observers have also been summarized by Galtsoff (1948).

As a result of the above investigations it has been established that the immediate cause of the Red Tide was an enormous and rapid but intermittent increase in numbers of a dinoflagellate which has been described in detail by Davis (1948) and named by him *Gymnodinium brevis*.

It was further established that a toxic material associated with the swarms of this organism was responsible for the death of fish in the area. The underlying cause of the dinoflagelate bloom has not been established, however. It may therefore be of value to discuss the factors which could reasonably account for this phenomenon, in the light of the conditions actually known to be present.

The enormous growth in numbers of planktonic organisms was not limited to *Gymnodinium brevis*, but, immediately after the loss of red colour due to the death of this species, large numbers of various other species were found. In all the samples of sea water examined at the

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time of, or shortly after, the outburst, the wet volume of plankton was very considerably in excess of samples taken on the west coast of Florida by members of this Laboratory on occasions previous to appearance of the phenomenon. Unpublished studies of waters in the Florida Keys over a period of several years which have been made by R. H. Williams indicate a low plankton content combined with a low content of inorganic phosphorus as the normal condition in these waters, at all times of the year. Wherever the presence of sewage has greatly increased the inorganic phosphorus content, the volume of plankton has also been found greatly to increase, although not to the extent characteristic of the Red Tide. It is therefore reasonable to assume that inorganic phosphorus is the principle factor limiting growth of plankton in these waters at all times. This is in agreement with the general body of observations on tropical or sub-tropical waters. The great growth of organisms during the Red Tide must consequently be associated with a considerable increase in the nutrient phosphorus available. The fact that the inorganic phosphorus content as determined at the time was too low to be detectable is of no consequence, since this element was probably by then completely used up by the plankton growth. Ketchum's observations here are particularly valuable since they show that the TOTAL phosphorus, dissolved organic, inorganic, and particulate was very considerably greater than that ever found previously under normal conditions in ocean water (Ketchum 1948). It is also interesting to note that R. H. Williams has detected phosphate phosphorus in a range of concentration of from 4 to 12 μg-atoms/liter in the Tampa Bay area, away from sources of human contamination during June 1946 (personal communication). The problem remains to account for the presence of this excess. (See Table I.)

Ketchum has suggested that the organisms may utilize the phosphorus over the entire water column and, by subsequent migration to the surface, concentrate the phosphorus there. Unfortunately, no plankton and chemical analyses were made of water at different depths, so that no direct evidence is available to support or refute this suggestion. There are several observations that may have an indirect bearing on the problem, however. As Ketchum has pointed out, unless the organisms have a facility for developing with far greater nitrogen deficiencies than ever measured previously or a remarkable ability to utilize atmospheric nitrogen, there must have been present in the water not only greatly increased quantities of TOTAL phosphorus but also of total nitrogen. The swarming theory would satisfactorily account for simultaneous concentration of both. The intermittent appearance and disappearance characteristic of the Red Tide would be readily explained under these conditions by the effect of winds, current, temperature changes and other factors promoting turbulence, which would quickly restore the phosphorus and nitrogen to the entire water column and thus bring conditions back to normal. In resolving the problem of the source of phosphorus this theory, unfortunately, presents a new difficulty. It now becomes necessary to explain why the swarming occurs at infrequent intervals separated by thirty years or more, and to explain what condition may stimulate or make possible swarming during Red Tide years alone. Without further knowledge of the life history, behavior, and physiology of *Gymnodinium brevis* this may be impossible to answer.

Phenomena such as upwelling of nutrient-rich deep water would satisfactorily explain an increase of nitrogen coincident with the phosphorus increase, but as Ketchum has pointed out the amount actually present was far in excess of what is normally present in deep water.

The measured amount of phosphorus present was so far above normal as to dispose of a previous suggestion by the present author (Gunter *et al.* 1948) to the effect that dissolved organic phosphorus might under certain conditions become more readily available.

A further possibility depends upon the presence of nutrient salts in bottom muds. The experience of Raymont (1947) and many other workers in adding fertilizer to bodies of water has been that a large proportion of the phosphorus added disappears from solution in an amount greatly in excess of the amount utilized by plankton growth and must necessarily have become incorporated with the bottom deposits. Unpublished observations of the present author have shown bacteria present in the calcareous muds of sponge grounds to the number of several million per cubic centimeter. Thus, while direct evidence is lacking, there is good reason to believe that both phosphorus and nitrogen may be present in the bottom deposits in quantities more than sufficient to account for Red Tide phenomena. Once more, however, a further problem arises of establishing the conditions or events which might release the nutrient salts from bottom deposits at infrequent intervals. Certainly no unusually heavy weather was associated with the Red Tide years (Gunter *et al.*). Furthermore, in normal years the waters in question, close to shore, contain considerable quantities of sediment originating from the bottom.

A possibility which cannot be ruled out completely is that the excess nutrient has its origin in mineral deposits. Florida is a major source of rock phosphate and it is not inconceivable that river drainage has brought increased concentrations of this into the ocean. The difficulty in this explanation lies in the fact that the Red Tide phenomena were observed near Key West and Cape Sable, which are at considerable distances from rivers which drain areas where phosphate deposits are known to exist. The prevailing drift of ocean water even at a distance of thirty miles from the west coast of Florida appears to be to the north (Smith, F. G. Walton 1941, and Marine Laboratory, University of Miami, 1948). It would be difficult therefore to explain how phosphates emptying into the ocean from rivers between Naples and Tarpon Springs could later appear near Key West. On the other hand, our knowledge of the surface wind drifts and alongshore circulation in this area is very inadequate and this possibility cannot be precluded.

The transport of phosphates to a wide area of ocean would be more readily explained on the basis of submarine deposits of the mineral which might become exposed periodically as a result of shifts in the bottom currents, which are known to be quite strong (Marine Laboratory, University of Miami, 1948). Virgil Sleight of the University of Miami Geology Department informs me that there is nothing in the literature which would rule out the presence of such deposits.

Other theories advanced previously have been so at variance with the facts that no useful purpose would be served in quoting them. It is also evident that theories of mineral origin suffer from their failure to account for nitrogen excess as well as phosphorus excess. The possibility of an ability on the part of *Gymnodinium brevis* to fix atmospheric nitrogen or to grow under conditions of extreme nitrogen deficiency has not been disproved, however. These theories, along with those previously mentioned cannot therefore be discarded before a careful study has been made. This should include not only observations on the physiology, behavior, ecology and life history of *Gymnodinium brevis* carried out under controlled laboratory conditions, but also an oceanographical chemical and biological survey of the Gulf waters near the west coast of Florida, and an examination of the bottom deposits in the area. The bottom deposits are particularly worthy of study in view of Nelson's recent findings (Nelson 1948).

Studies of the streams reaching the Gulf on the northern part of Florida's west coast are, it is understood, already in progress. In order that the part played by mineral deposits may be thoroughly examined it is hoped that these may be extended to the ocean and that the necessary experimental work outlined above will also be undertaken by competent investigators.

TABLE I—PHOSPHATE PHOSPHORUS DETERMINATIONS

Location	Date	μ gram-atoms Liter
North side of Big Bird Key, Terra Ceia Bay, R. H. Williams	June 3, 1946	4.80
Middle of Terra Ceia Bay, R. H. Williams	June 3, 1946	3.60
East side of Green Key, Hillsborough Bay, R. H. Williams	June 4, 1946	12.0
One mile west of Green Key, Hillsborough Bay, R. H. Williams	June 4, 1946	8.4
Neighborhood of Sarasota, B. H. Ketchum	July, 1947	4.5 to 7.4

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